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Behavior Analysis of a Ferrofluidic Gyroscope Performances

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Abstract

In this work a gyroscope using a ferrofluidic mass as inertial mass is presented. The device consists of a glass plate filled with de-ionized water with an injected ferrofluidic drop, a electromagnetic driving system to move the ferrofluidic mass back and forward along the actuation axis and a differential inductive readout system to sense the motion of the ferrofluidic sphere. An angular rate imposed to the device produces a deviation of the ferrofluidic mass trajectory which is measured by the differential readout system. Experimental surveys have been performed to characterize both the driving system and the behavior of the device.

Keywords: Ferrofluidic gyroscope; inertial sensor; differential sensing.

1. Introduction

Inertial sensors with high performances are growingly demanded for applications requiring absolute motion, vibration and shock measurements [1]. Advanced topologies and innovative materials conferring to the device reliability, robustness, high sensitivity and high resolution are largely inspected. Among different materials, ferrofluids show interesting features which make them suitable to cope the above mentioned requirements. Ferrofluids are biphasic systems made up small solid ferromagnetic particles suspended in a liquid, generally water or solvent and covered with a thin polymeric layer (surfactant) to prevent their agglomeration caused by Van der Waals forces [2]. A magnetic field applied to a ferrofluidic volume exerts a magnetic force which causes the alignment of the ferrofluidic particles in the direction of the field. Moreover, under particular conditions, a ferrofluid volume subjected to magnetic force can behave like a mass connected to tunable equivalent spring whose properties can be controlled by modulating the driving magnetic field amplitude. Interesting examples of a ferrofluidic devices are given in [3-4]. In particular, the inclinometer presented in [3] exploits two ferrofluidic cushions to reduce friction forces acting on the magnetic core when an external tilt is applied. In [5-6] innovative ferrofluidic transducers are presented. In particular, in [5] a ferrofluidic pump was realized; in this device a ferrofluidic mass, inside a pipe filled with de-ionized water, acts both as valve and as plunger to move the fluid from a inlet to an outlet. In [6] the device exploits a ferrofluidic mass free-to-move inside a glass pipe filled with de-ionized water; a readout strategy senses the mass position which depends on the applied tilt. The idea to use ferrofluids as the active mass in inertial sensors offers the opportunity to control the device specifications by manipulating the ferrofluidic

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core properties (such as viscosity, volume, etc.) via electric signals [7]. Moreover, the absence of mechanical moving parts and solid-inertial masses provides high reliability and robustness against mechanical shocks [7]. Moreover, the decoupling between the electric tools (the driving and the readout systems) and the beaker housing the ferrofluidic mass confers interesting features to the device such as isolation between the electric tools and the liquid media, the re-usability of the electric tools while the low cost beaker becomes the disposable part of the system, the possibility to implement such sensing strategy to preexisting structure filled with a liquid media.

2. The device

The ferrofluidic gyroscope developed is intended to sense an angular rate applied to the beaker housing the ferrofluid volume acting as inertial mass. Absence of mechanical moving parts and solid-inertial masses, robustness against mechanical shocks, decoupling between electric and mechanical parts and low cost are the main advantages of the approach proposed. The device consist of a glass plate filled with de-ionized water in which a drop of ferrofluid is injected. Such mass moves between two stable positions due to magnetic forces generated by two electromagnets placed under the plate. The electromagnets are driven by two sinusoidal signals out of phase of 180° each other. A schematization of the device is given in Figure 1. Above the already described structure, two permanent magnets are placed under the magnetic actuators to implement a retaining mechanism against the Coriolis force.

Fig. 1. Movement of ferrofluidic mass along the driving axis.

The readout electronics consists in two planar coils whose inductance values change with the ferrofluid motion. Actually, when a angular rate is forced to the device, the pseudo-linear trajectory of the ferrofluid volume is perturbed producing an alteration of the magnetic coupling with the sensing coils. Figure 2 shows a schematization of the readout electronics implemented which performs a complete processing of signals coming from the differential sensing system.

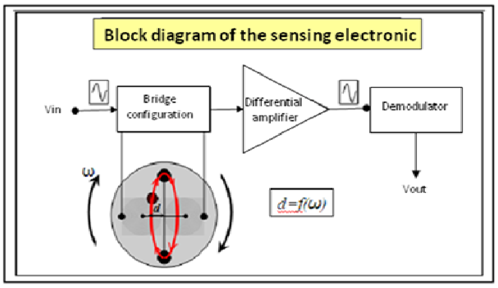

Fig. 2. Block diagram of the sensing electronic.

A preliminary release of a ferrofluidic gyroscope has been presented in [8]. In this paper, a novel release of the hardware implementing the device and the set-up for its characterization are presented along with results obtained through a deep investigations of the device behavior. Figure 3 shows the new set-up adopted for the device characterization implemented by a step-motor and including a high resolution encoder to obtain an independent estimation of the imposed angular rate. Specifications of the (ELCIS I/38Z4-2000-5-BZ-H-CVC-R-01) encoder adopted are given in Table 1. A dedicated software tool has been developed to manage the step-motor thus controlling the imposed angular rate and to acquire data coming from the encoder and the sensor readout system.

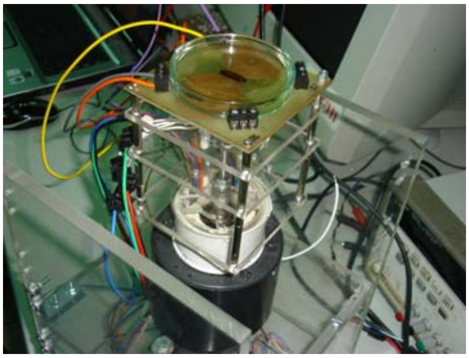

Fig. 2. Experimental set-up adopted for the device characterization.

Encoder specifications	
Pulses per round	1÷2000
Max. frequency	160KHz
Output signal	Push-pull
Voltage supply	5Vcc

Table 1. Electrical parameters of encoder.

3. Experimental results

In the following, considerations leading to the definition of the optimal working conditions especially in terms of the driving signals amplitude and frequency are discussed along with a preliminary experimental characterization of the device.

A set of experiments have been performed to characterize the behavior of the ferrofluidic mass subjected to the driving system. In particular, an experimental set-up based on a vision system has been developed to estimate the trajectory of the ferrofluidic mass. A set of frames have been acquired for different values of the frequency and amplitude of the driving signals. In order to process the acquired images a dedicated software environment has been developed based on tracking the ferrofluid volumes position along its trajectory. To such aim standard filtering paradigms has been used which allows for particle detection. Figure 4 shows a typical frame and the superimposed grid with a resolution of 5mm.

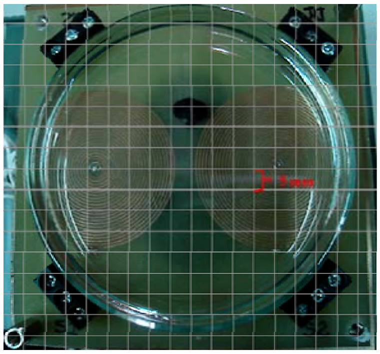

Fig. 4. Frame and superimposed grid with a resolution of 5mm.

The reconstruction of the mass trajectory was performed for two different tilt (0° and 3.58°) of the device (see figure 5)and for a mass of 0.1ml of EFH1 ferrofluid. Observations highlight different behavior of the ferrofluidic mass as a function of the driving signal, showing an optimal region of amplitudes and frequencies for which the mass trajectory follows the driving dynamic. To such aim both frequency and time analysis of the driving signal and the reconstructed trajectory have been implemented. A driving parameter map highlighting the optimal working region is shown in Figure 6.

In order to characterize the device response a set of experimental surveys has been performed. In particular, the device response for different values of the angular rate imposed to the device has been observed. The working conditions of the driving system has been selected on the basis of the analysis above illustrated which. In particular, a driving signal of 1.4Vpp@780mHz has been used. Figure 7 shows the behavior of the device as a function of the imposed angular rate, the latter being estimated by the encoder system

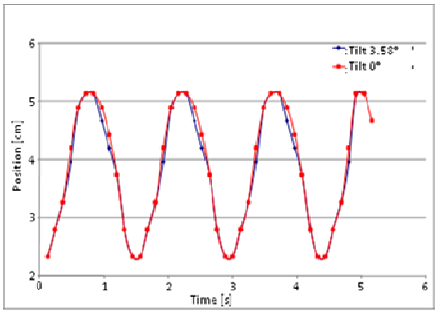

Fig. 5. Time evolution of the ferrofluidic mass (0.1ml) position for a driving signal of 1.4 Vpp @780 mHz for two different tilt.

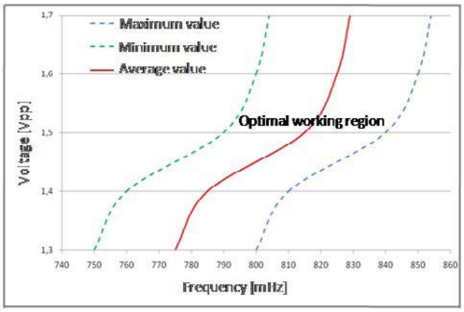

Fig. 6. Driving parameter map highlighting the optimal working region.

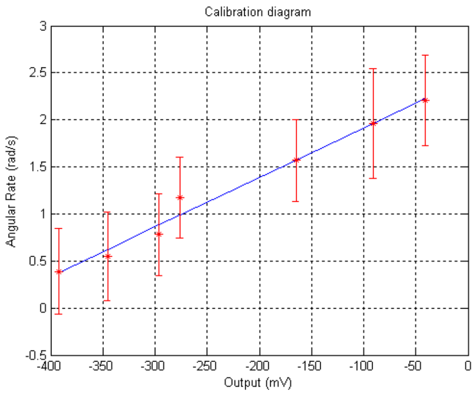

Fig. 7. Calibration diagram of the ferrofluidic gyroscope.

Figure 7 shows a linear trend of calibration diagram. The value of estimated sensitivity is due probably to experimental noise. Works are in progress to improve the performance of the device.

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